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Bioastronautics Initiative

Spacecraft Fire Safety Research Program

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Microgravity Combustion Science Branch
NASA Glenn Research Center

Sixth International Microgravity Combustion Workshop
Cleveland, Ohio
May 22 – 24, 2001

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Microgravity Combustion Research at Glenn Research Center

- **Microgravity combustion research conducted to date has impacted fire safety practices and procedures on STS and ISS**
  - Shut off ventilation flow upon start of fire event rather than deploy a fire extinguisher.
  - Minimization of the enriched oxygen environments on spacecraft.
  - JSC recognition that margin of safety presupposed for material flammability in microgravity is in fact absent.

"We can say with near-certainty that the probability of the initiation of an accidental fire event during the lifetime of ISS is unity – whether the fire transitions into a serious problem or not will depend on our collective knowledge of low-gravity fire prevention, detection, and suppression." ***– NASA Combustion Science Discipline Working Group in a letter to Dan Goldin (2001)***

- **Partial gravity levels introduce additional complexities**
  - Lunar habitat - 0.16g; Martian habitat - 0.38g
  - Combined effect of diffusion, radiation, conduction, and convection can produce unique results

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NASA Bioastronautics Initiative – Combustion Science

- **Substantially improve spacecraft fire safety within six years**
  - $1M per year for four years (initial funding level)
  - Grant-based through NRAs and directed research
- **Fire safety practices and procedures**
  - ISS and Shuttle operations
  - Prolonged human-crew missions in Earth orbit and beyond
  - Lunar and/or Martian habitats
    - In-situ resource utilization
    - Propellant manufacture and storage

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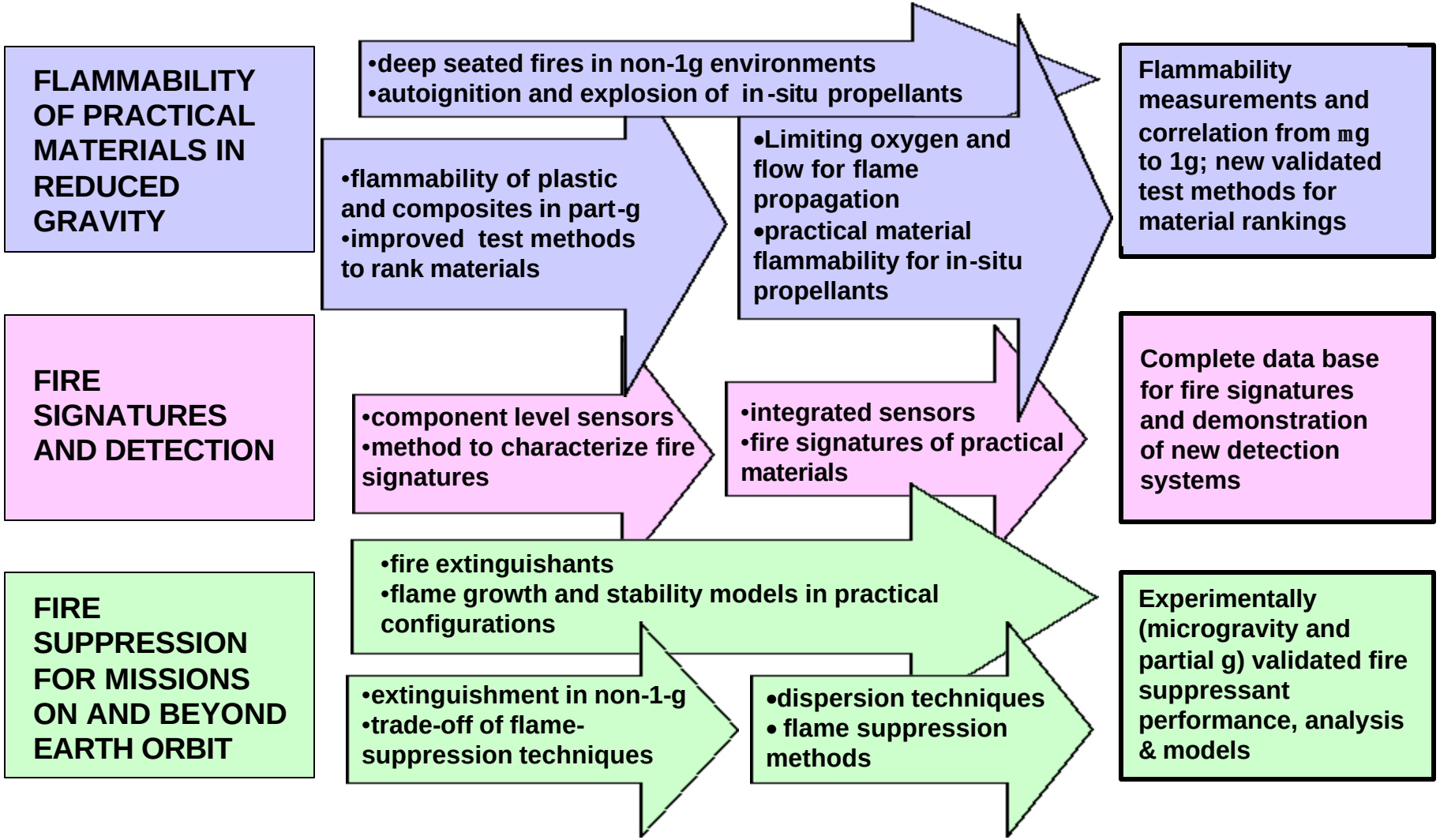
Fire Safety On and Beyond Orbit



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Microgravity Fire Safety Research

- **Over 20 projects funded by 1995, 97, 99 NRAs that address fire safety in spacecraft**
  - Flame spread across liquid pools (expt'l and compt'l)
  - Flammability of solids
  - Concurrent and opposed-flow flame spread
  - Flame spread on wire insulation
  - Smoldering and transition to flaming
  - Flame spread in partial gravity environments
  - Thickness effects on flammability
  - Flammability of polymers (expt'l and compt'l)
  - Ignition delay of polymeric fuels

- **Bioastronautics Initiative has allowed additional projects to be funded to help to build a coherent program**

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Microgravity Fire Safety Projects (99 NRA)

- **Development of an Earth-Based Apparatus to Assess Material Flammability in Low-Convection Environments for Microgravity and Extraterrestrial Fire Safety Applications** ***(PI: Olson, NASA GRC; co-I: Beeson, Haas – NASA JSC-White Sands)***
- **Material Properties Governing Co-current Flame Spread in Microgravity** ***(PI: Torero, University of Maryland)***
- **Two-Dimensional Smoldering and Transition to Flaming in Microgravity** ***(PI: Fernandez-Pello, UC-Berkeley; co-PI: Urban, NASA-GRC)***
- **Secondary Fires: Initiation and Extinguishment**
  (PI: Ross, NASA-GRC; co-PI: Urban, NASA-GRC; Mell, Univ. of Utah)
- **Characterization of Smoke from Microgravity Fires for Improved Spacecraft Fire Detection** ***(PI: Urban, NASA-GRC; co-I: Mulholland, Cleary, and Yang, NIST; Yuan, NCMRfc)***
- **Physical and Chemical Aspects of Fire Suppression in Extraterrestrial Environments** ***(PI: Takahashi, NASA-GRC ;co-I: Linteris, NIST, and Katta, ISS, Inc.)***

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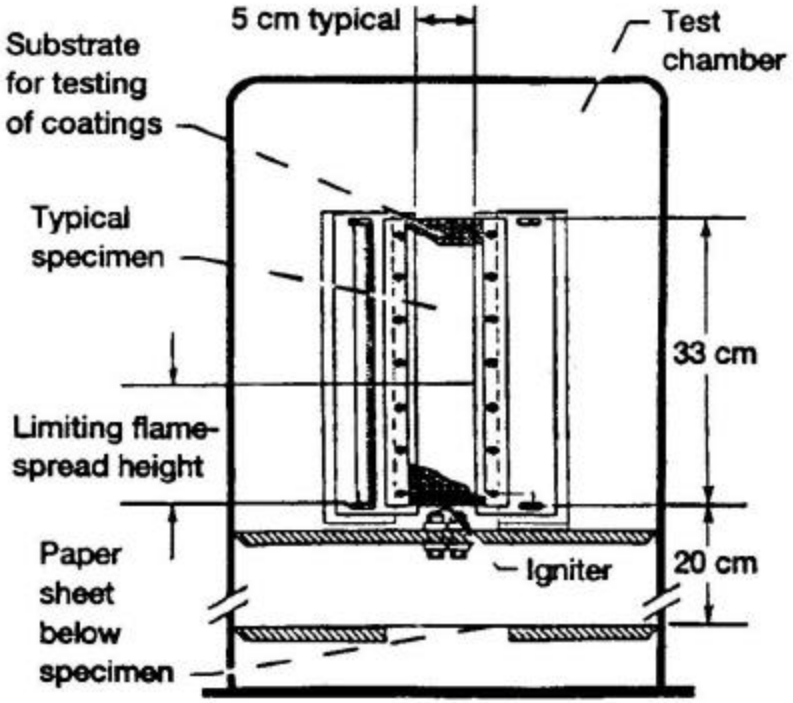
Upward Flame Propagation Test

- **Exposure to ignition source for 25 sec**
- **Acceptable if flame fails to propagate away from the ignitor for a distance of less than 15 cm**
  - Cannot scatter hot particles capable of igniting a paper sheet mounted below the specimen



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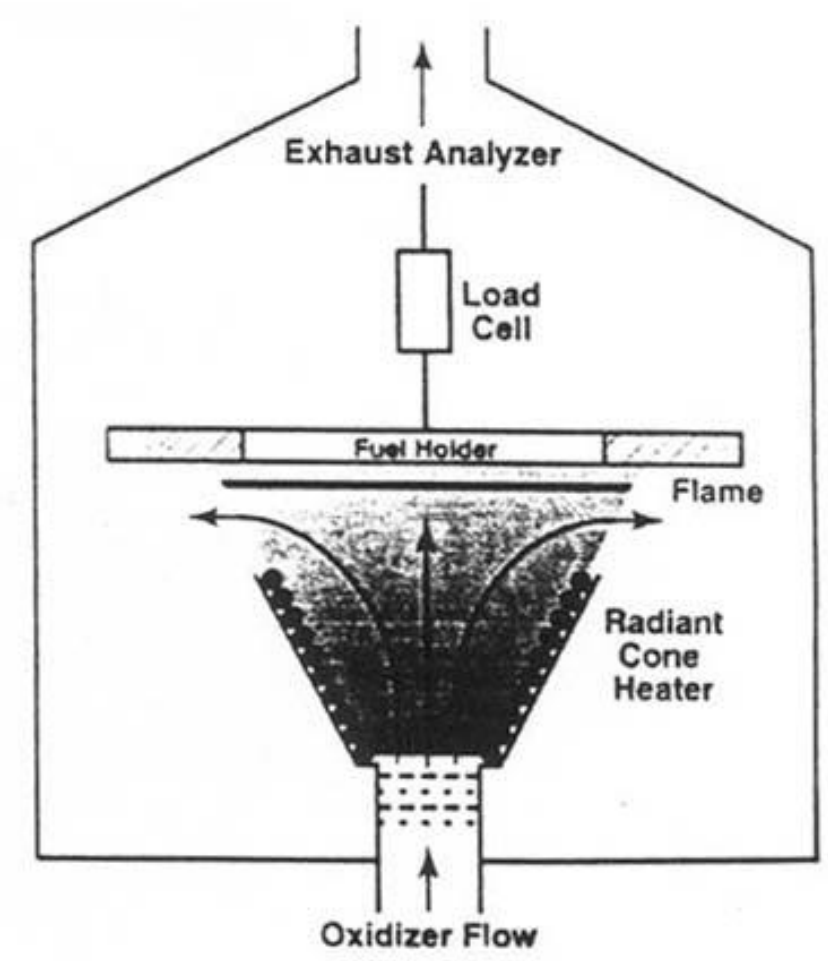
Proposed Material Flammability Test

- **Development of an Earth-Based Apparatus to Assess Material Flammability in Low-Convection Environments for Microgravity and Extraterrestrial Fire Safety Applications**
  - PI: Olson, NASA GRC; co-I: Beeson, Haas – NASA JSC-White Sands
- **Develop and test apparatus to assess material flammability and flame extinction limits**
  - scale low-stretch flame environments
- **Develop a predictive model to evaluate overall material flammability**
  - data derived from tests



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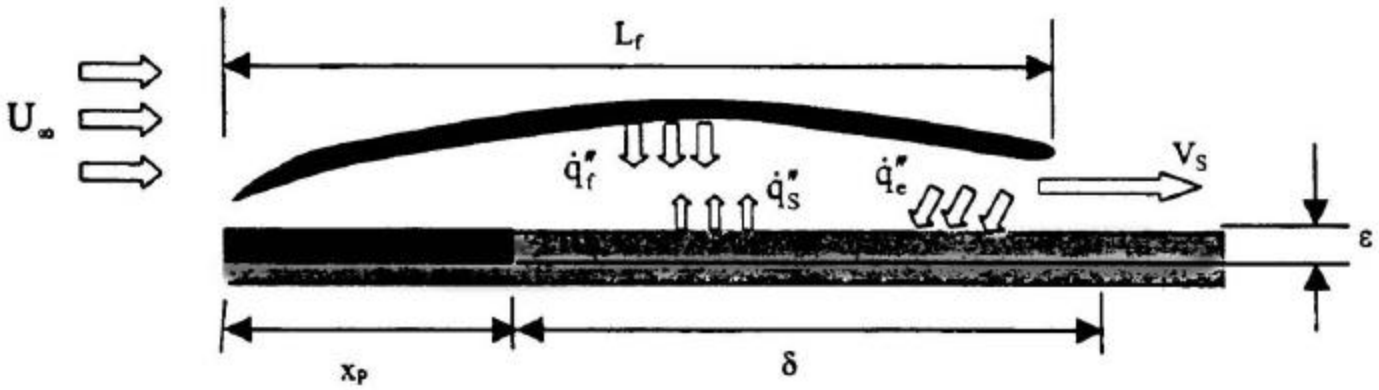
Quantitative Analysis of Upward Flame Spread Test

- **Material Properties Governing Co-Current Flame Spread in Microgravity**
  - PI: Torero, University of Maryland
- **Model normal gravity flame-spread in Upward Flame Spread Test**
- **Extract representative mass transfer number**
  - Rank material flammability
  - Quantitative evaluation for risk assessment



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Smoldering Combustion

- **Probable fire scenario**
  - proximity of polymeric materials to overheated electrical cables, circuit boards, etc.
- **Two-Dimensional Smoldering and Transition to Flaming in Microgravity**
  - (PI: Fernandez-Pello, UC-Berkeley; co-PI: Urban, NASA-GRC)
- **Follow-on to Microgravity Smoldering Combustion (MSC)**
  - GASCAN - 1995-1996
  - Polyurethane foam slabs
- **Investigate smolder of polyurethane foam slabs**
  - Effect of oxidizer flow velocity, O_2 concentration, and external heating on smolder rate

Smolder unsustained in air at 0-g

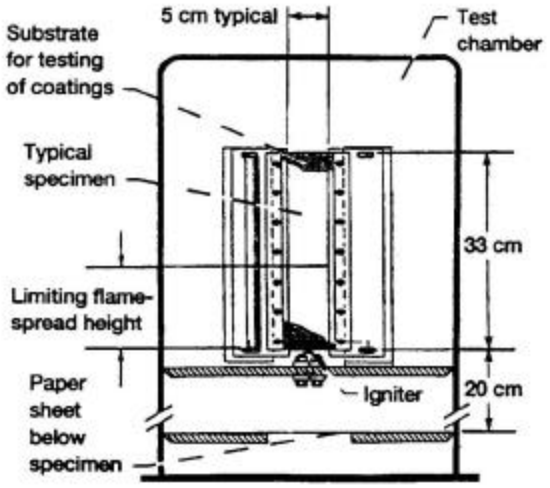
Smolder sustained in 40% O_2/60%N_2 in 0-g

Secondary Fires

- **Small flaming or smoldering fire may ignite other on-board material**
  - Passage of an initial premixed gas, firebrand, or aerosol flame
  - Free-floating burning material expelled during combustion of effervescing materials
    - Plastics
    - Nylon Velcro strips
    - Wire insulation

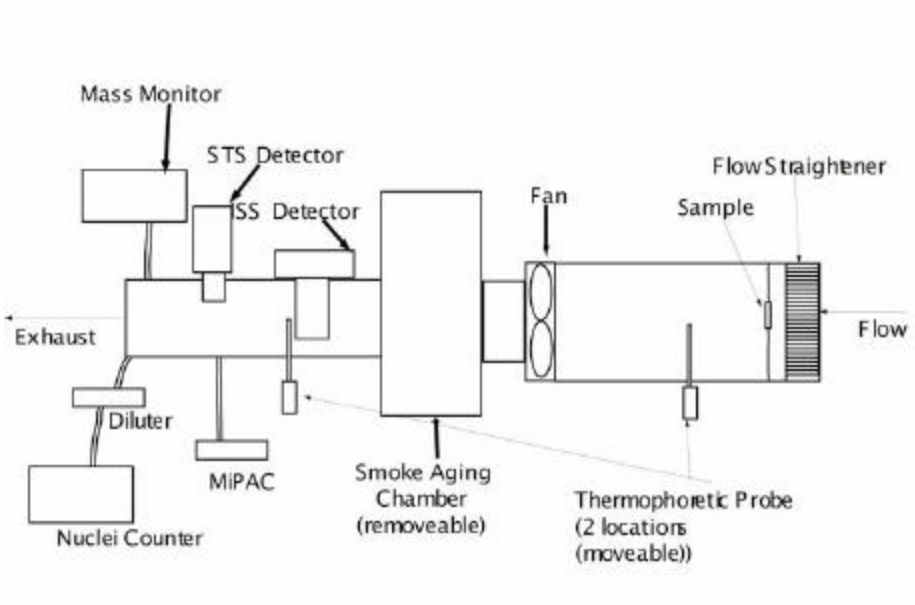
- **Secondary Fires: Initiation and Extinguishment**
  - PI: Ross, NASA-GRC; co-PI: Urban, NASA-GRC; Mell, Univ. of Utah

- **Investigate conditions at which firebrands can initiate secondary fires**
  - Firebrands simulated using individual or a stream of burning fuel drops



Fire Signatures and Detection

- **Characterization of Smoke from Microgravity Fires for Improved Spacecraft Fire Detection**
  - PI: Urban, NASA-GRC; co-I: Mulholland, Cleary, and Yang, NIST; Yuan, NCMRfc
- **Comparative Soot Diagnostics (CSD)**
  - STS-75 Glovebox
  - Evaluated STS and ISS smoke detectors for solid smoke particulates
- **Measurement of size distribution of liquid smokes**
  - Rubber, paper, plastic
  - Evaluation of STS and ISS detectors
- **Methodology to predict growth of smoke droplets**
  - Fuel pyrolysis, thermo properties, and flow environment



Fire Suppression

- **Physical and Chemical Aspects of Fire Suppression in Extraterrestrial Environments**
  - PI: Takahashi, NASA-GRC ;co-I: Linteris, NIST, and Katta, ISS, Inc.
- **Measure critical extinction mole fraction for various fire suppression agents**
  - CO_2, H_2O (mist), N_2, CF_3Br, CF_3H, and CF_4
  - Cup burner
- **Tests to be conducted in KC-135 aircraft**
  - Simulate Lunar and Martian gravity levels
- **Compare results with 2-D unsteady fire suppression code**
  - Kinetic models for CH_4-O_2 combustion
  - Diluents and halogenated agent chemistry

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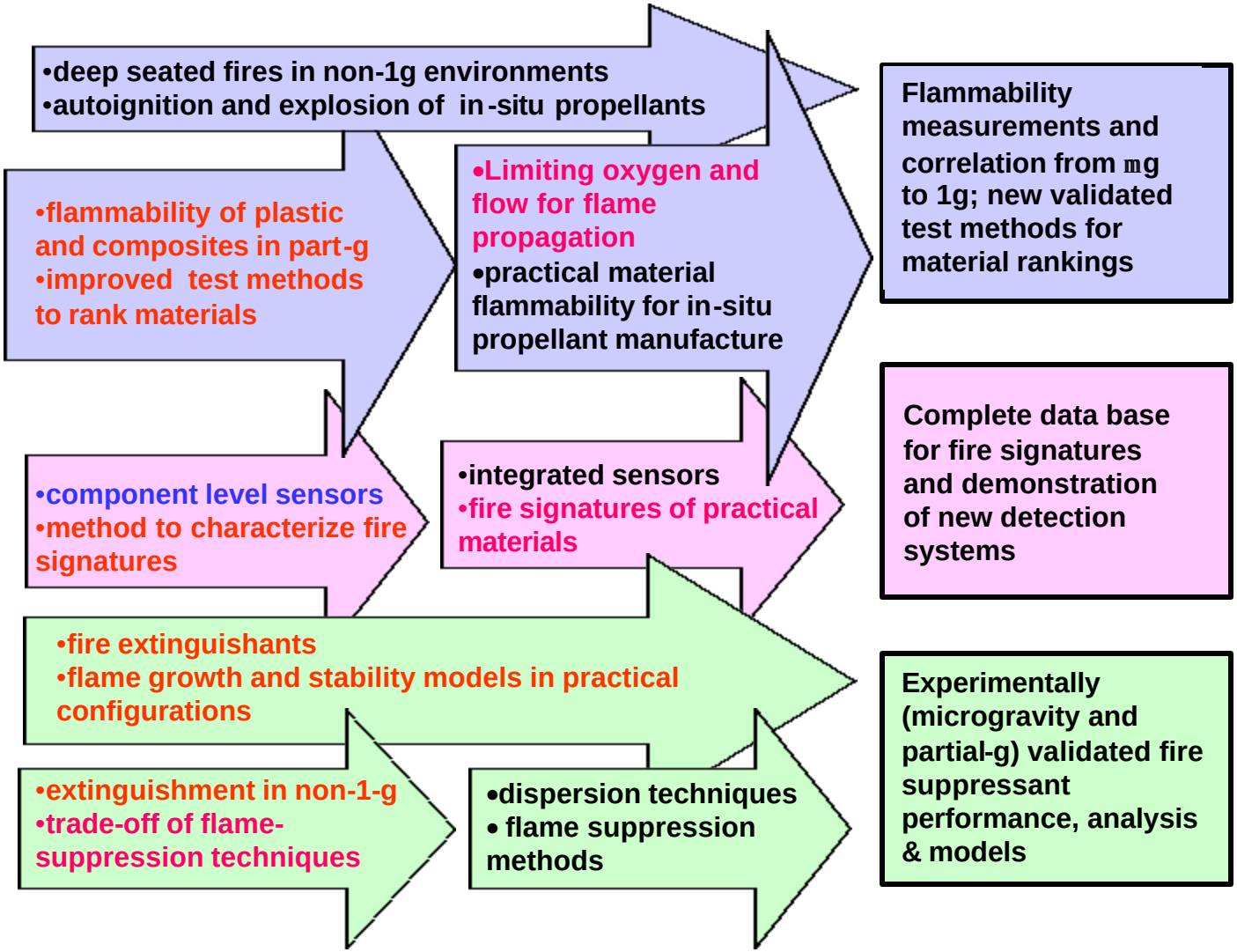
Fire Safety On Orbit and Beyond



Future Work

- **Material Flammability**
  - Deep-seated fires
  - Fire initiation and flammability of radiation shielding, waste disposal, trash storage, laundry, manufacturing processes
- **Fire Signatures**
  - Smoke, gas products, heat, radiation and pressure rise are different in low-g
  - Implementation of “electronic nose” technology requires accurate identification of fire and pre-fire signatures
- **Fire and Post-fire Response**
  - Smoke/particulate transport with confined volumes
  - Effectiveness of low-velocity CO_2
  - Re-ignition upon diffusion of O_2
  - Production, transport, and reduction of fire and suppressant contaminants

Future Work

- **Fire safety aspects of in-situ resource utilization and propellant production**
  - Fire safety concerns for high-T, high-P O_2 handling
  - Performance and efficiency of propulsion, fluids, and combustion processes in partial-g

Program Schedule

- **Spacecraft Fire Safety Workshop – June 2001**
  - Sponsored by NASA Glenn Research Center
  - Working group oriented workshop to:
    - Identify research needed for fire safety of STS, ISS and their payloads
    - Identify fire safety concerns for prolonged human-crew missions in Earth orbit and beyond
    - Anticipate research for future Lunar/Martian habitats
  - NASA SP released by Fall 2001
- **2001 NASA Research Announcement – November 2001**
  - Goal-oriented Initiative
- **Spacecraft Fire Safety Workshop – 2003**
  - Review progress and outline research priorities next four years

Summary

- **Spacecraft fire prevention, detection, and suppression techniques and procedures adapted from terrestrial and aircraft systems**
  - Experience gained in U.S. space operations
- **Limited practical fire safety data obtained in reduced gravity**
  - Working understanding of combustion processes
  - Unknowns remain concerning flammability, flame spread, fire signatures, suppression effectiveness, *etc*.
  - Differences between 1-g and low g can have undesirable consequences
- **NASA's Bioastronautics Combustion Science Initiative**
  - Substantially improve spacecraft fire safety within six years
  - Current research addresses appropriate areas
  - Focus area in upcoming NRA (Goal-oriented Initiative)
  - Workshops and interactions in technical forums help to guide future programs